Effects of Benthopelagic Animals on Seabed Properties

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ONR Contract N00014-98-C-0442
http://www.aard.tracor.com

LONG-TERM GOALS

The long-term goals of this research are to improve the ability of benthic biologists and biological oceanographers to observe life on and in the seabed; to describe the interactions between the animals that live there, their neighbors and their food; to improve our understanding of the coupling between the benthic and the pelagic communities; and to assess biologically mediated changes in those physical properties of the seabed that affect the scattering and penetration of sound from and into the bottom.

OBJECTIVES

Direct observation of animals that live on or in the seabed is exceptionally difficult. This is especially true in areas with characteristically poor visibility or in water that is too deep to allow divers to spend much time near the bottom. Little attention has been given to developing instrumentation and sensors that would allow remote observation of benthic animals for long periods at high spatial and temporal resolution. We are developing high frequency acoustic sensors, sensor deployment and data processing methods to fill this gap, thereby improving the information that benthic ecologists can access about benthic and benthopelagic animals and the seabed environment. Monitoring bottom and near-bottom animal distributions and processes at intervals of minutes and resolutions of tens of cm or better may

Report Documentation Page	Form Approved OMB No. 0704-0188

1. REPORT DATE **30 SEP 2001**	2. REPORT TYPE	3. DATES COVERED **00-00-2001 to 00-00-2001**
4. TITLE AND SUBTITLE **Effects of Benthopelagic Animals on Seabed Properties**		5a. CONTRACT NUMBER
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **BAE SYSTEMS,,Integrated Defense Solutions,Analysis and Applied Research,,4669 Murphy Canyon Road,,San Diego,,CA,92123**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S)
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**		
13. SUPPLEMENTARY NOTES		
14. ABSTRACT		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**7**	

also be useful in determining the causes of short term temporal changes in acoustical scattering and sound propagation in the seabed over a wide frequency band.

APPROACH

The Sediment Acoustics eXperiment (SAX-99), sponsored by ONR's biological oceanography, geophysics and acoustics programs was carried out in the Gulf of Mexico near West Destin, FL in the fall of 1999. We used multi-frequency acoustical monitoring sensors at 265, 420, 700, 1100, 1850 and 3000 kHz to detect the emergence and re-entry of small benthopelagic crustaceans at dusk and dawn (Alldredge and King, 1980). This behavior changes the millimeter-scale roughness of the seabed at least twice a day. Interactions with currents at the seabed can also trigger behaviors involving vertical migration (Roman, Holliday, and Sanford, 2001). Animals may also burrow into the seabed, changing the volume heterogeneity of the subsurface in the upper meter or two. These two phenomena have been identified as likely contributors to an observed anomalous penetration of the seabed by sound in the kHz and tens of kHz frequency range (Thorsos, Jackson and Williams, 2000; Lopes, 1996). An excellent overview of the SAX-99 experiment will be found in two recently published multi-author papers. Richardson, et al (2001) contains a summary of the physical and biological environment and processes that we observed as a group before and during the major occupation of the SAX-99. A second paper, also a group effort (Thorsos, et al 2001), provides an overview of the many acoustical measurements that were made during the SAX-99 effort. Peter Jumars (University of Maine, Darling Marine Center), Liko Self and Jill Schmidt (University of Washington) and David Thistle (Florida State University) provided ground truth data by deploying several kinds of emergence traps.

WORK COMPLETED

This fiscal year, we focused on an examination of SAX-99 data from our three TAPS zooplankton sensors. Our interest was in the identification of changes at time scales characteristic of biological activities. We have completed our analysis for about 2/3 of the data we collected. We have contributed material for two publications directed at a special issue of the IEEE Journal of Ocean Engineering (Richardson, et al 2001; Thorsos, et al 2001) and presented two papers at the fall 2000 meeting of the Acoustical Society of America. We have participated in several principal investigator meetings (e.g., Bangor, WA and Stennis Space Center, MS). We have also used resources from this project to prepare material for use in an overview paper on bioacoustical sampling (Holliday, 2001), which includes a section on the flux of animals between the seabed and the water column. Data from this research have been included in a chapter for a new book on acoustical oceanography (T. Leighton and G. Heald, eds.).

RESULTS

We identified the movements of zooplankton and micronekton between the sediments and the water column (emergence and re-entry), and temporally related foraging activities of nekton as important causes of bioturbation at this site. A multi-frequency scattering record (Fig. 1) illustrates the variability in the distribution of marine organisms with depth and time at this site. Larger benthic organisms, such as sand dollars and crabs, undoubtedly also modify the local topography and sediment properties but the sensors we deployed in this experiment were not designed to describe their movements.

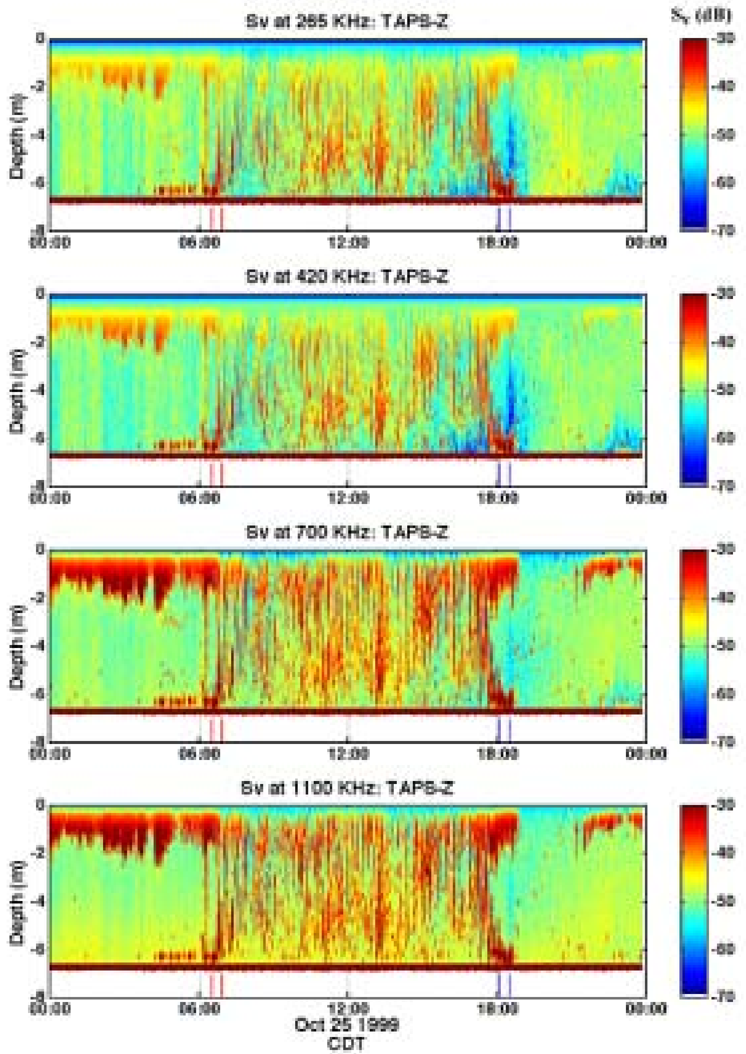

Figure 1: Twenty-four hours of the volume scattering strength record at four of the TAPS frequencies are shown for October 25, 1999, starting and ending at midnight (CDT). Measurements (24 ping averages) were made once per minute. Fish began to aggregate near the seabed about 0400 hours, possibly anticipating the entry of benthopelagic zooplankton into the bottom as they arrived from the water column at dawn. The fish then dispersed into the water column to forage during the daylight hours. A similar pattern of aggregation was observed during the twilight period, presumably in anticipation of the emergence of the zooplankton and micronekton that forage in the water column at night. The mooring's float acted as a Fish Aggregation Device (FAD) during most of the dark hours and appears to have attracted numerous fish during daylight hours as well.

An examination of the acoustic records from the three TAPS units we deployed suggests that seabed emergence of organisms consistently occurs after sunset. That emergence, however, is sometimes very rapid (e.g., ca 10 min) and at other times it appears to be over an extended period of several hours. The record (Figure 1) from one of the down-looking TAPS units for the 24-h period from midnight on October 24, 1999 to midnight Central Daylight Time on October 25, 1999 illustrates a typical pattern

of sound scattering for this site. (SAX-99 participants agreed to use Central Daylight Time for the entire experiment, even into November).

The moon was full on October 24, so approximately 99% of the moon's visible disk was illuminated after moonrise at 1825. The moon set at 0736 on October 25. Civil twilight began at 0631 on October 24 and the sun rose at 0656. Sunset was at 1806 and civil twilight ended at 1830. These times are indicated as short vertical lines in each panel of Fig. 1, below the echo from the bottom.

During the day, and into the twilight and dawn hours, fish appeared to be attracted by the large white float used to position the down-looking TAPS at about 6.5 m off the bottom (Fig. 1). Presumably they could visually orient on the float long after they could not see each other sufficiently well to school. During the day, individual fish and small schools occupied the 6.5-m water column under the TAPS most of the time. The emergence on this particular day appeared to be gradual or more diffuse than was the case on other days when a sharp increase could be observed as the zooplankton left the bottom. On this day, the aggregation of the fish near the bottom in anticipation of prey masked the lower level echoes from the plankton and micronekton.

Fish appear to begin aggregating near the bottom several hours before sunrise, possibly in anticipation of the re-entry into the seabed of zooplankton that had been feeding during the night in the water column. A similar pattern can be seen before sunset, where fish appeared to be aggregating in anticipation of an emergence event. Although we had no gut contents to examine, we speculate that the fish moved from the central water column to positions near the seabed in anticipation of the appearance of prey. There should clearly be an advantage in foraging on a 2-D plane (the seabed) at dawn and dusk as opposed to foraging in 3-D (the water column) after dark. It seems likely that once an organism begins to emerge from the seabed, successful escape by making a rapid re-entry when under attack by a fish is problematic at best. The "pock marks" made by bottom foraging fish and recorded by several principal investigators in SAX-99 (e.g., the photo by Lyons in Fig. 12(b) of Richardson, et al 2001) are evidence of this feeding strategy.

These predator-prey interactions change both the local bottom roughness at centimeter scales and the physical characteristics within and near the localized disturbances created when the fish feed in this manner. This, in turn, changes the local acoustical impedance, modifying both the propagation and scattering of sound from and within the seabed. Our data indicate that biological activity by both predator and prey, and the consequent changes in scattering that result may not be evenly spread over the day. Thus, sound may penetrate and propagate in different ways throughout the day in response to these biological behaviors.

IMPACT/APPLICATION

Observation of aquatic animals in their natural environments remains a major challenge in both biological oceanography and limnology. Critical processes in feeding, reproduction, growth and predation occur at scales from fractions of millimeters up to scales that match the ambits of individuals. We believe that high frequency, high resolution acoustical sensors can play a part in improving our ability to sample and observe benthic animals and the benthic environment. This should be particularly so in environments where visibility is limited by either resuspension or by a nephaloid layer. Sound also has the advantage that it can penetrate the seabed, making possible observations of near surface animals and the structures that they build in the bottom.

The seabed and the zone that lies immediately below the water / sediment interface are dynamic environments, not static ones. Both physical processes and biological ones play important roles in the degree of consolidation of the sediments, the heterogeneity of the bottom and the changes that take place over different temporal scales. These processes impact the seabed properties that control acoustic scattering, the coupling of sound into the bottom, and the propagation of sound along the surface and in the bottom. All of these phenomena potentially impact naval operations in shallow water, where mine warfare and ASW operations must be conducted prior to engaging in expeditionary warfare.

TRANSITIONS

The observations made in our part of the SAX-99 program offer explanations for at least some of the variability one observes in acoustic scattering from the seabed and in the penetration and propagation of sound within the bottom. Understanding these phenomena at a level that will eventually allow modeling and prediction of both absolute scattering and propagation, and the variability in those quantities from descriptions of the physical and biological environment, are long-term goals of a large community of academic, industry and navy scientists.

RELATED PROJECTS

This work was done in part as a contribution to a team effort. ONR Code 32, under the auspices of a Departmental Research Initiative on High Frequency Scattering from the Seabed, formed a team of principal investigators from multiple institutions to examine the reasons for observed anomalous sound penetration into the seabed. We have relied on information freely shared by many of the SAX-99 investigators at some point in our analyses, but our principal interactions have been with the "biology team" - Peter Jumars and Liko Self (http://www.ume.maine.edu/~marine/jumars/paj.html), Jill Schmidt and David Thistle, all of whom have related ONR-funded projects. A fairly comprehensive list of the SAX-99 participants can be found in the list of authors for the IEEE special issue (Thorsos, et al 2001; Richardson, et al 2001) as cited in the References below. We have also found that data collected at this site revealed a transient appearance of a "thin layer" of zooplankton, which has been useful in another of our ONR research programs.

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